Using resonant soft X-ray scattering to image patterns on undeveloped resists

Guillaume Freychet, I. Cordova, D. Kumar, T. McAfee, C. Anderson, P. Naulleau, C. Wang and Alexander Hexemer

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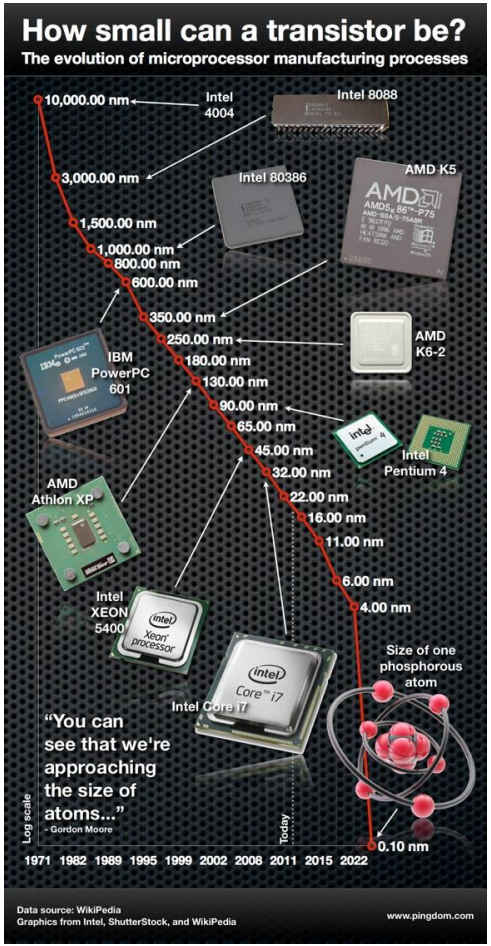
CAMERA AM Applied Math

ALS ADVANCED LIGHT SOURCE

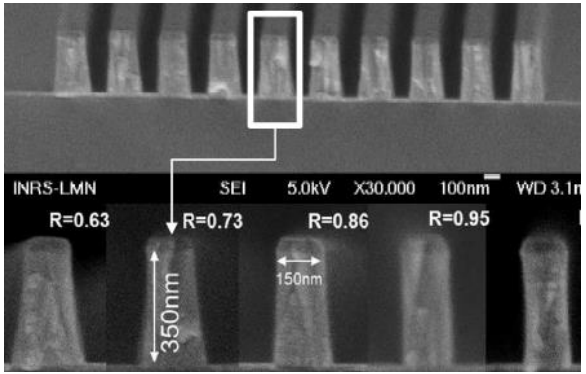


Context for the semi-conductor industry

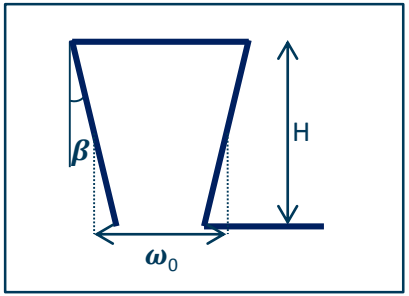
Parameters to control :

- ✓ Pitch
- ✓ Linewidth
- ✓ Line height
- ✓ Roughness
- ✓ Sidewall angle

Sub-nm resolution

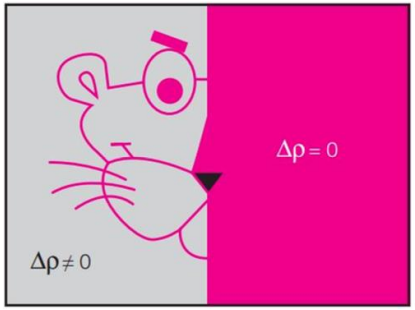


1D array : Line gratings



With the size reduction of the objects, any sub-nm defects will impact strongly the performance of the device

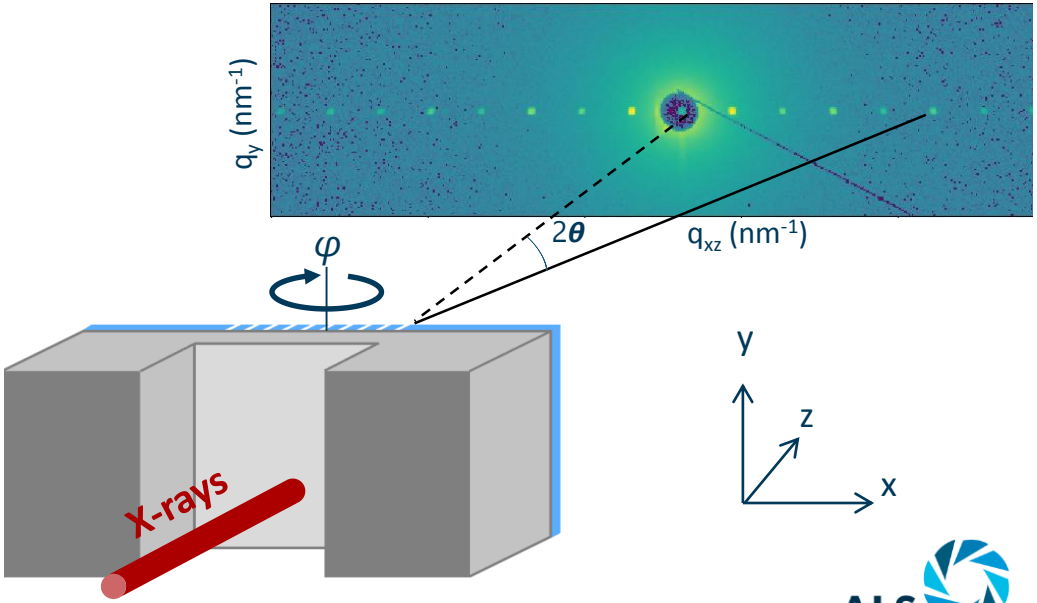
Small Angle X-ray Scattering (SAXS)

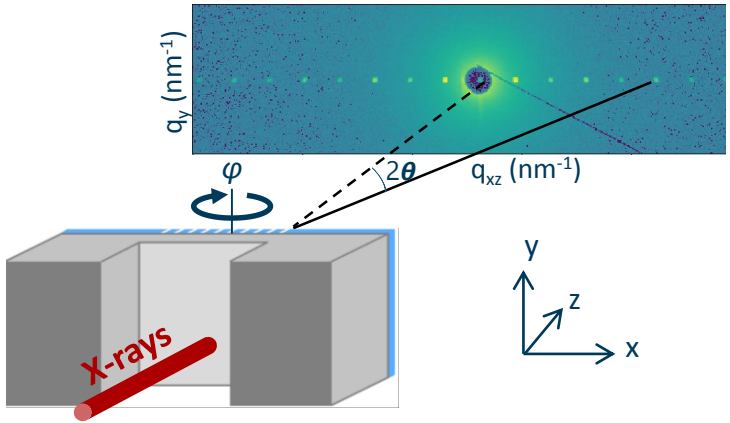


✓ Probe electronic density contrast

✓ Small angle scattering: probe 1-1000 nm

$$q = \frac{2\rho}{l}\sin 2q$$

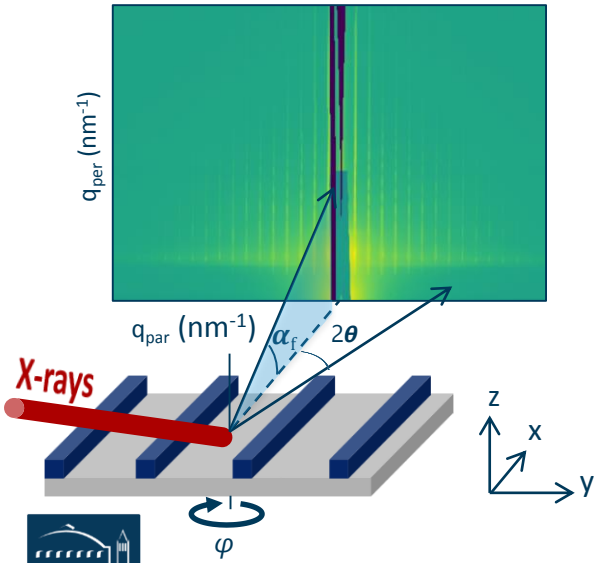




Small Angle x-ray scattering (SAXS) on line gratings

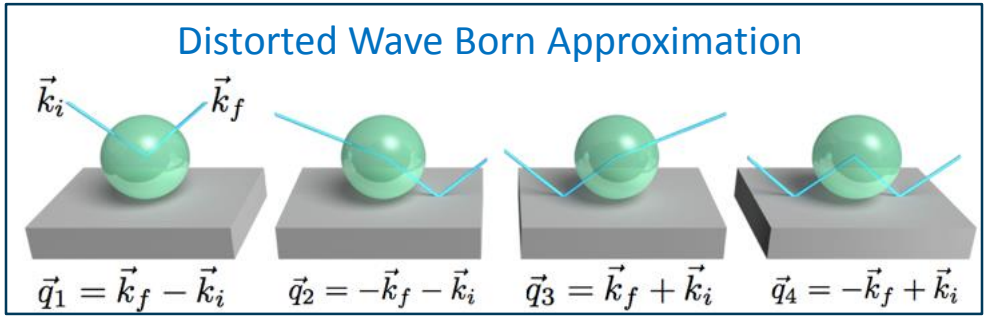
- ✓ Transmission configuration
- ✓ High energy x-ray source

D. F. Sunday et al., ACS Appl. Mater. Interfaces (2017)



Grazing-incidence SAXS (GISAXS)

- ✓ Small incidence angle < 0.2 deg
- ✓ Probe thin films **on Silicon wafer (700 µm)**



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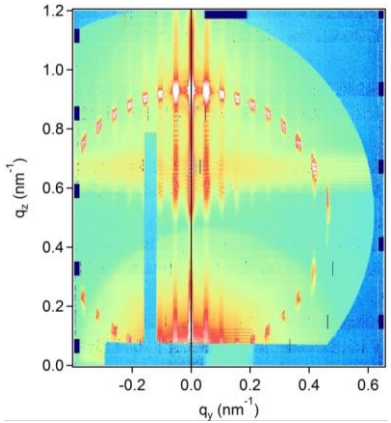
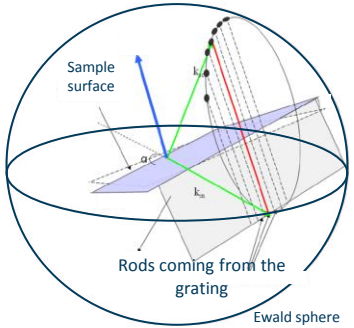
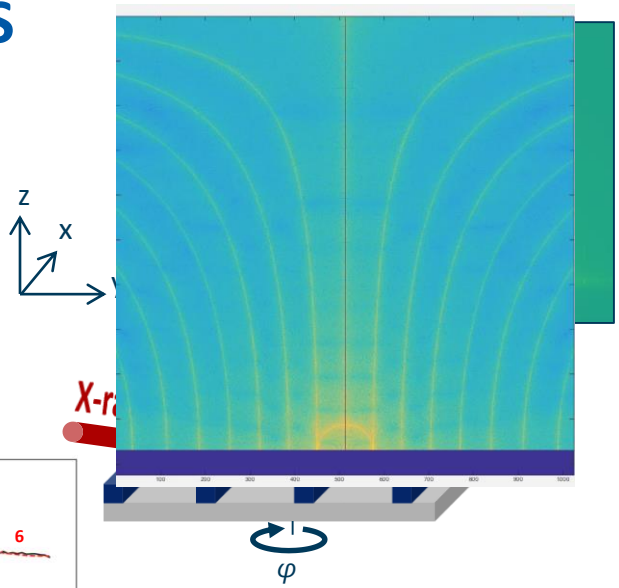
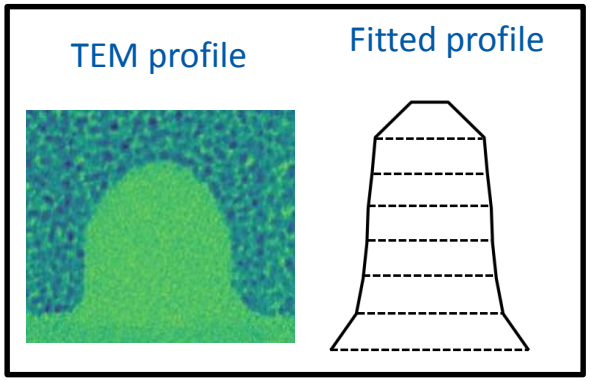
Critical-Dimension GISAXS

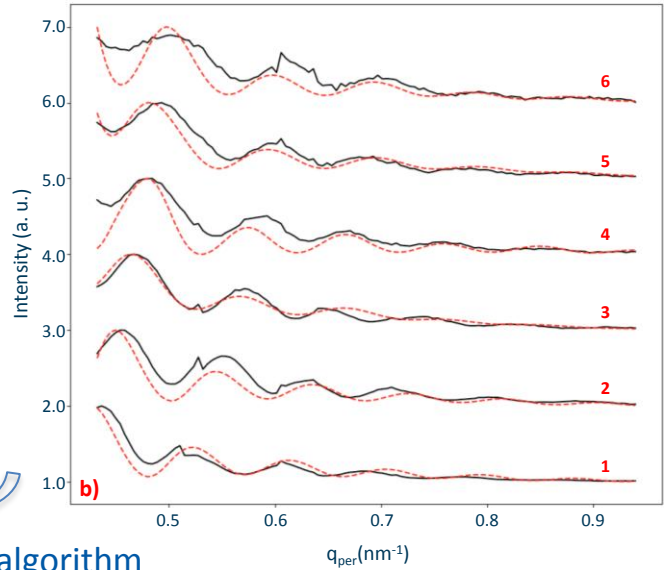




Rotation of the gratings (along z)







1D vertical cut

Fit using genetic algorithm

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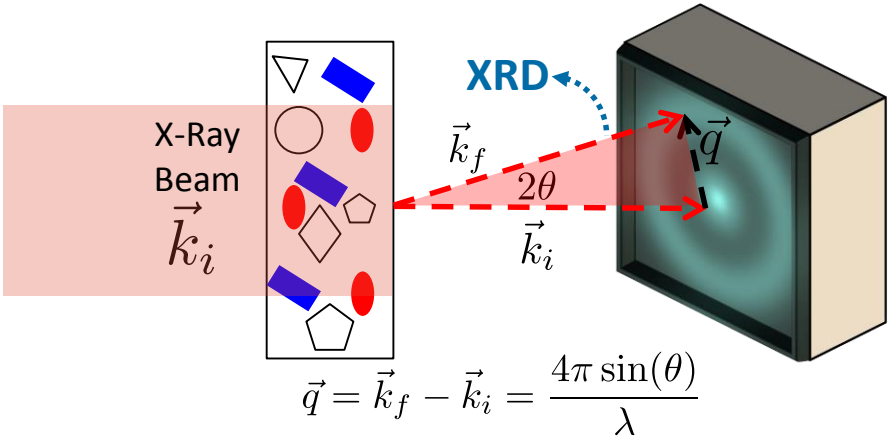
Resonant Soft X-Ray Scattering (RSoXS)

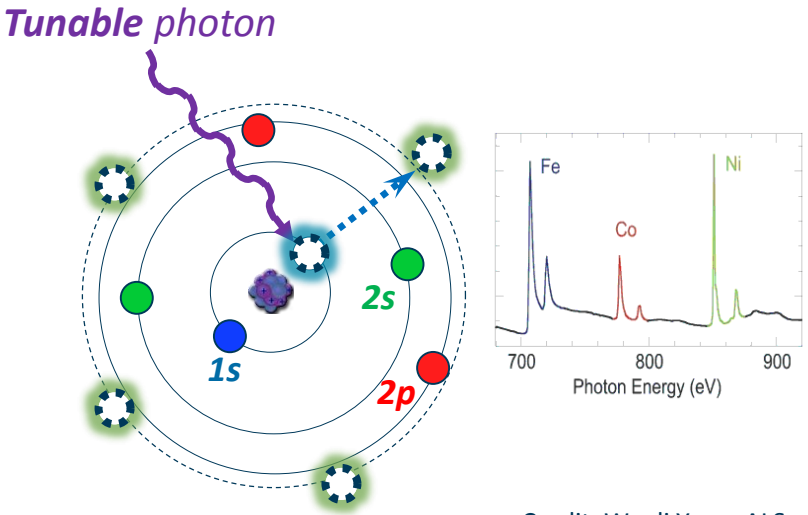
Reconstruction of a latent image (before removal of the exposed resist)

Small Angle X-Ray Scattering



Credit: Guinnier A. *et al*, *Ann Phys,* **1939,** 12:161–237

X-Ray Absorption



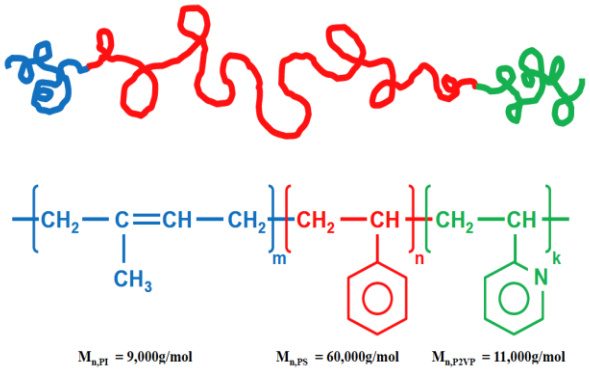
Credit: Wanli Yang, ALS

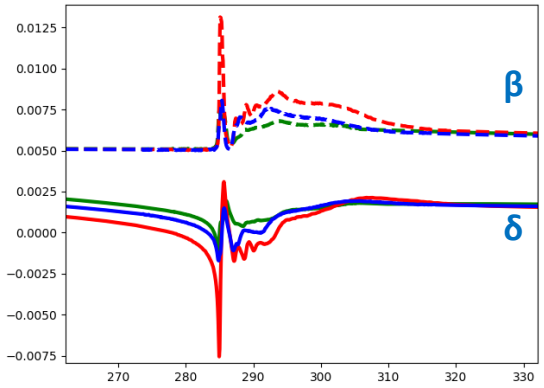
Electronic density:

$|\delta^2 + \beta^2|$

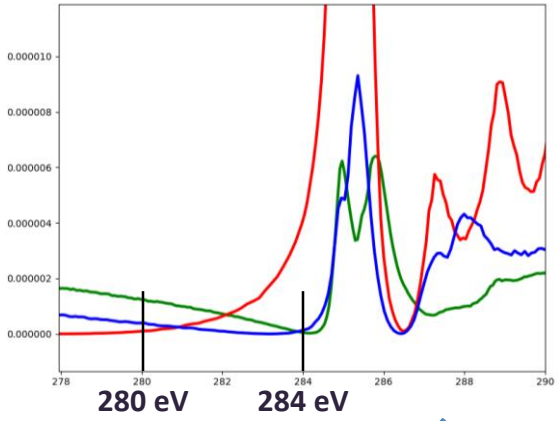
RSoXS applications

Triblock copolymer:

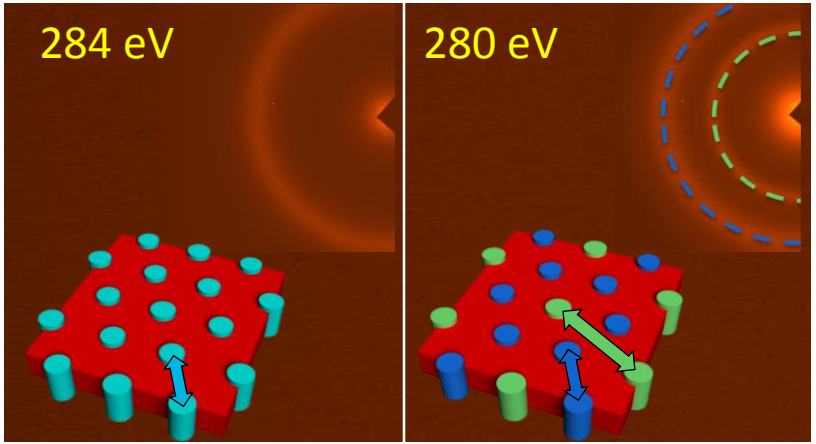




Electronic density $|\delta^2 + \beta^2|$



- ✓ Tune the energy to enhance the scattering contrast
- ✓ Before the absorption edge to reduce beam damage



Credit: C. Wang *et al*, *Nano Lett.*, **2011**, 11, 3906

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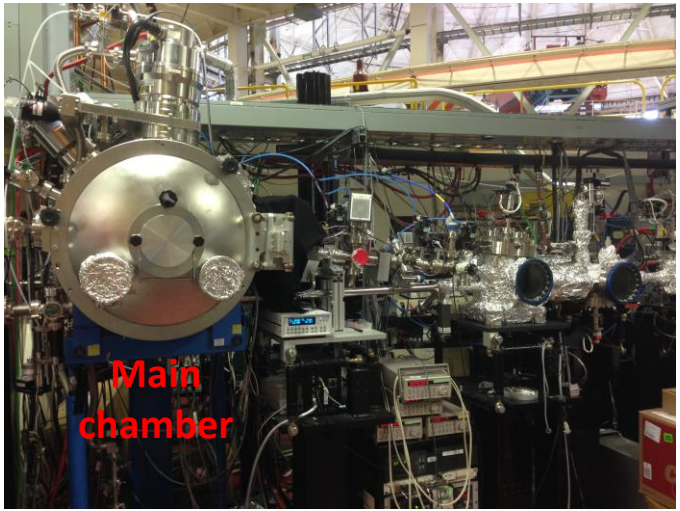
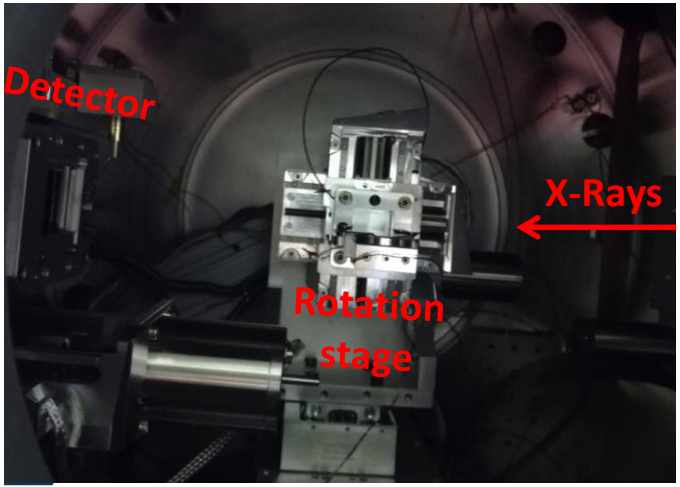
11.0.1.2 Beamline at the ALS





C. Wang

I. Cordova

Wavelength (nm)

Atomic Number

CD-GIRSOXS of latent image

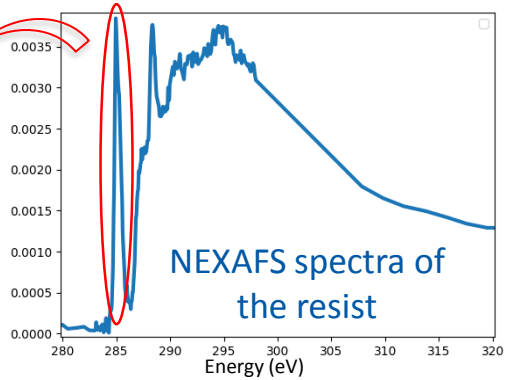
Chain-scission EUV resist:

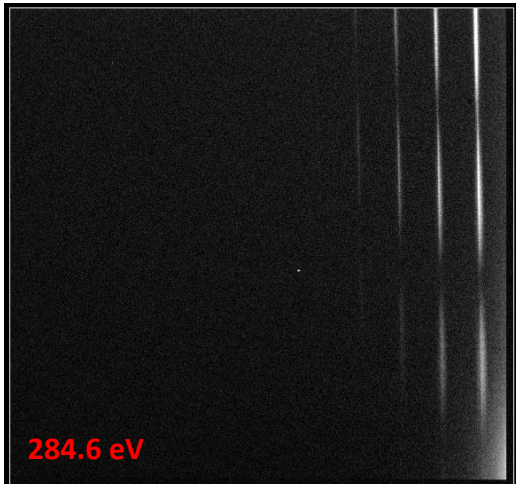
- ✓ E-beam exposition
- ✓ 200 nm pitch line gratings
- ✓ Post-Exposure baking

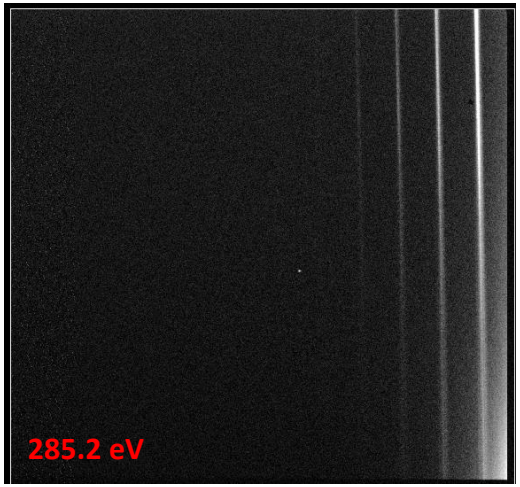
Exposition + bake:
Chain scission

Modification of the carbon environment
Modification of the β and δ
Introduction of a scattering contrast

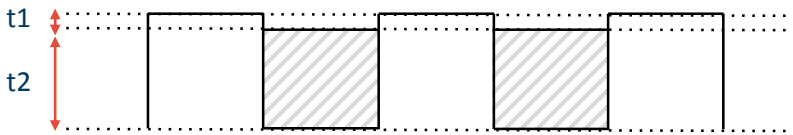
Peak related to a specific carbon bonds







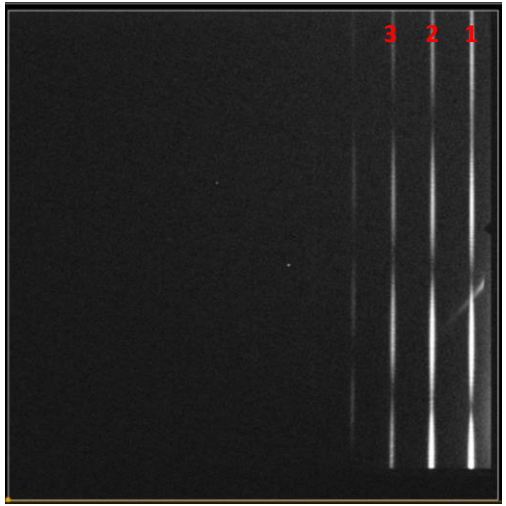
- ✓ **284.6 eV: Electronic density contrast**
- ✓ **285.2 eV: No electronic density contrast**



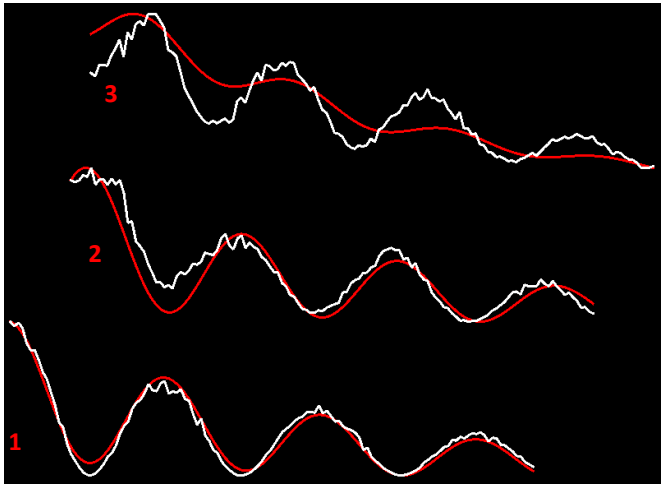
Contrast between exposed/unexposed resist at 284.6 eV

CD-GISAXS of latent image using Resonant scattering

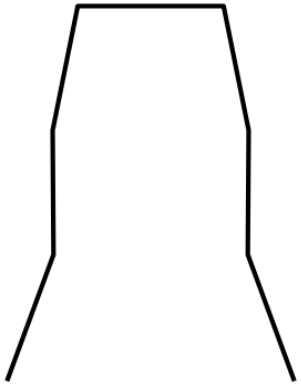
Reconstruction of the 3D shape of a latent image



1D vertical cut



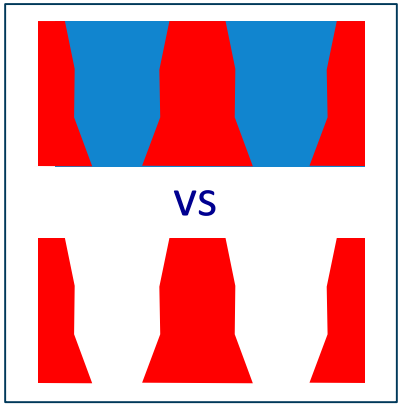
Extracted profile



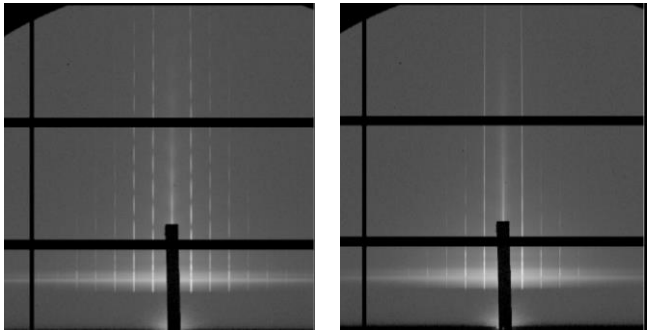
- ✓ New perspectives to control the 3D shape of a latent image
- ✓ Short measurement time: 10 seconds
- ✓ Beam damage?

Conclusion

- ✓ 3D reconstruction of the latent image with a sub-nm resolution
- ✓ Trapezoidal shape after the exposition
- ✓ Comparison before and after development



- ✓ Test on different resists (different elements edges)
- ✓ Quantification of the roughness
- ✓ Study beam damage on the sample



FEM wafer (IMEC)

Acknowledgements

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Weilun Chao
Christopher Anderson

Daniel Staaks
Scott Dhuev
Peter Ercius

Thank you for your attention!


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